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A proposal of VnR-based dynamic modelling activities to introduce students to model-centred learning

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Abstract

We propose a laboratory learning pathway, suitable for secondary school up to introductory undergraduate level, employing the VnR dynamic modelling software. It is composed of three increasingly complex activities dealing with experimental work, model design and discussion.

Introduction

Learning processes can strongly benefit from a model-centred approach since the basic physics concepts are initially dealt with in a specific context so as to ensure comprehension. Once they have been correctly grasped, they just need to be recalled and applied by analogy in other relevant contexts.

Modelling is an important means to develop a scientific approach to problems since it helps students to get used to identifying the relevant variables and the relations between them, formulating hypotheses, and designing experiments suitable for testing such hypotheses [1]. We present a learning pathway, suitable for secondary school up to introductory undergraduate level, by which to introduce students³ to model-centred learning by means of the VnR dynamic modelling software [2].

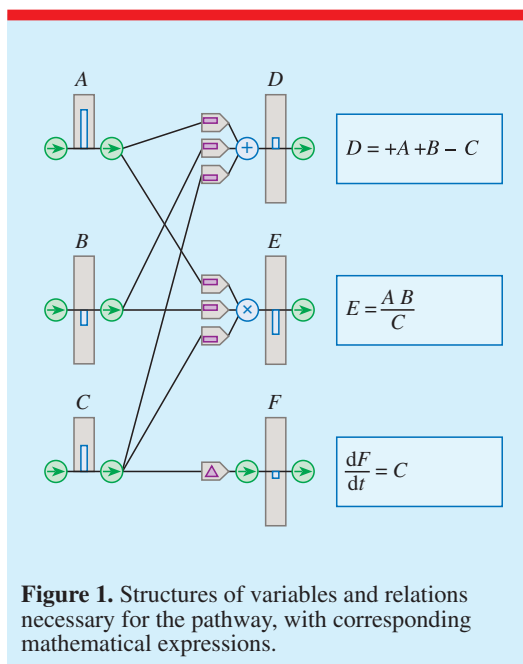
³ A pilot experimentation with the pathway was done with students of the Faculty of Education at the University of Modena and Reggio Emilia. The results reported in this article refer to this experimentation.

VnR basics

VnR is a dynamic modelling software whose characteristics are especially suited to students who are required to understand the nature of science but generally have a weak grounding in mathematics [3]. In VnR, the design of models is performed by means of icons. Figure 1 synthesizes all the relations among variables necessary for this pathway⁴, with corresponding mathematical expressions. Column-like icons, whose height stands for intensity, represent *variables* that can be positive only (A, B, C) or positive/negative (D, E, F). Links between variables represent *relations*, either static (sum, product, and their inverses, e.g. links from A, B, C to D, E) or dynamic (rate of change, e.g. the link from C to F).

Once the model structure has been completed, the user starts the calculation and an animation of the variable evolving over time is displayed. VnR provides complementary display tools such as the ‘model in words’ function, i.e. a written

⁴ The rest of the relations between variables present in VnR are threshold switches, rarely used and not relevant for this work.



explanation of the model structure in each of its variables and relations, a graphical representation of the evolution of variables over time and a slider allowing the user to replay the animation. Several equivalent model structures are possible for a single phenomenon and the user is free to draw their own model structure according to their own perspective. Various solutions can be easily compared by recognizing recurring elementary structures which can be referred to elementary physics concepts.

Goals of the learning pathway

These didactical activities were designed to improve the ability to recognize and manage models as cognitive tools. Thanks to the VnR-based learning pathway, students should be able to achieve the following goals:

- learn how to think in terms of variables and relations;
- identify elementary structures as components of more complex models;
- recognize similarities between different phenomena;
- develop an approach to phenomena as processes evolving over time.

Organization and expected results of the activities

The pathway is organized into three activities, each of them structured as follows:

- observation of a phenomenon (either shown by the teacher or directly experienced by the students);
- individual representation of the observed phenomenon, building and testing of a VnR model, and discussion in pairs on the similarities and differences in the model structures;
- plenary discussion, chaired by the teacher, aimed at analysing to what extent various model structures are consistent with the observed phenomenon.

Each activity has an average duration of four hours.

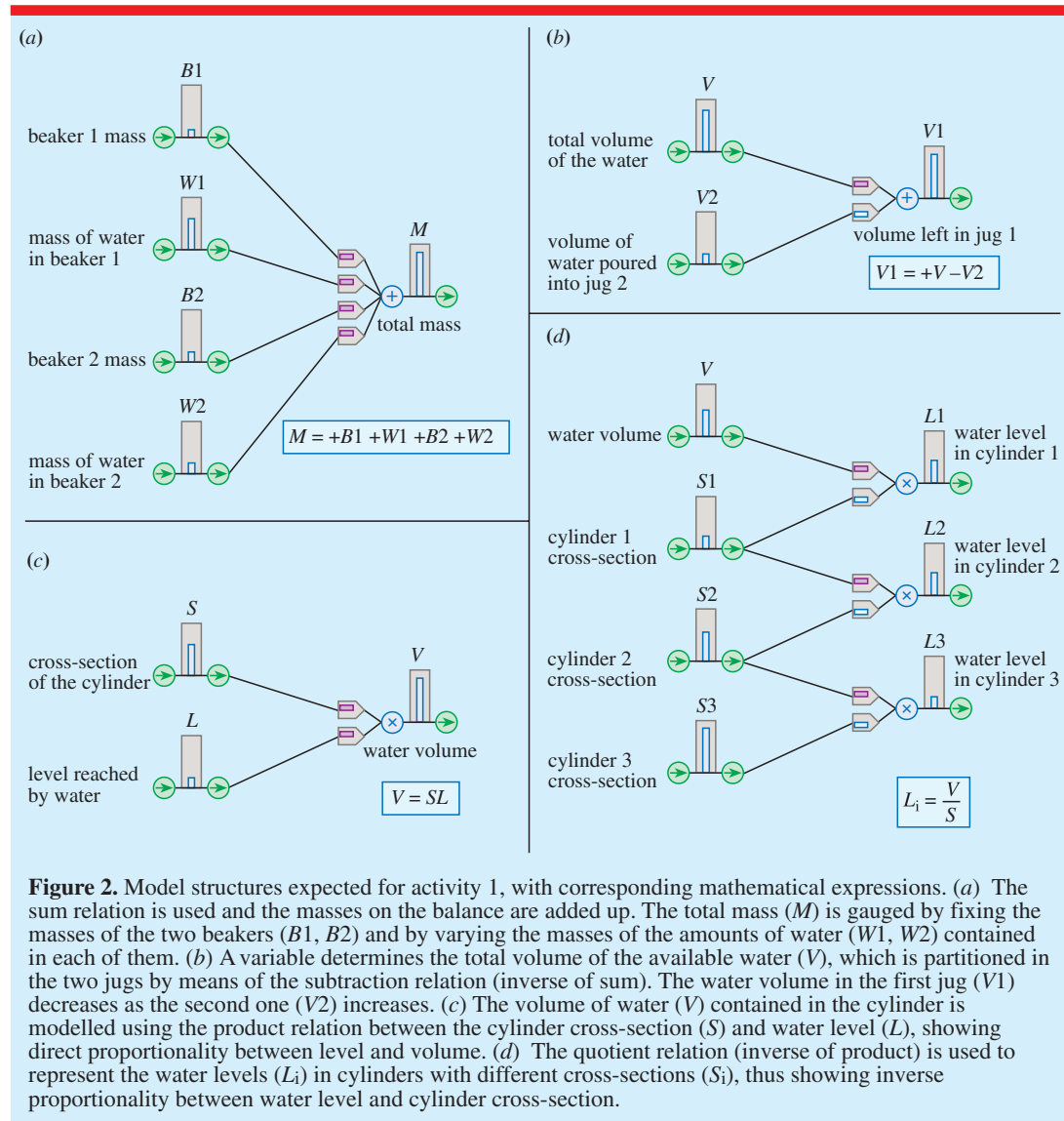
Activity 1. Experiments with simple static model structures

Activity 1 aims to train students to work in the VnR environment and to deal with variables and static relations.

The teacher proposes the following steps:

- Observation:** different amounts of water are poured into two different beakers on a balance.
Task: the students are expected to model the mass measured by the balance.
- Observation:** water is poured from a full jug into an empty one.
Task: the students are expected to model the water volumes contained in the jugs.
- Observation:** water is poured up to a certain level into a cylinder with a given cross-section.
Task: the students are expected to model the water volume contained in the cylinder.
- Observation:** the same amount of water is poured into three cylinders with different cross-sections.
Task: the students are expected to model the levels reached by the water in the three cylinders.

In order to help students to correctly identify the variables, it is necessary to ask them to label the variable icons carefully with meaningful names.



Possible model structures for the four proposed phenomena are reported in figure 2. The letters (a), (b), (c) and (d) refer to the phenomena described above.

Activity 2. Different laboratory experiments with the same model structure

Activity 2 introduces the positive/negative variables and the 'rate of change' relation in dynamic modelling. Students should notice that the same model structure can describe different phenomena and that elementary structures representing basic physics concepts recur in different phenomena.

Students, in small groups, perform three different experiments on evolution towards equilibrium by measuring the amount of an extensive physical quantity flowing between two communicating systems as a function of time. Experiments (see table 1) are based on the following:

- water flow between two cylinders connected by a pipe (communicating vessels);
- charge redistribution between two parallel capacitors connected through a resistor;
- transfer of thermal energy from hot water contained in a vessel immersed in an

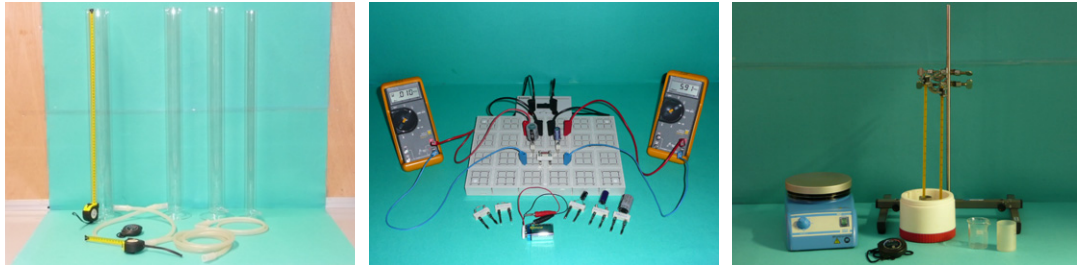


Figure 3. Equipment available for the experiments of activity 2.

Table 1. Similarities between the experiments of activity 2.

#	Experiment	Extensive quantity	Conjugated intensive quantity	Reservoir	Capacitance	Resistor	Resistance
I	Communicating vessels	Water volume	Water level	Cylinder	Cross-section of the cylinder	Pipe	Hydraulic resistance ^a
(ii)	Parallel capacitors	Charge	Potential	Capacitor	Capacitance	Resistor	Resistance
(iii)	Thermal energy transfer	Heat	Temperature	Water mass	Thermal capacity	Container wall	Thermal insulation ^b

^a Comprising the effects of the pipe impedance and of the fluid viscosity.

^b Inverse of thermal conductivity.

insulating basin containing cold water (bain-marie).

The available equipment (figure 3) allows repeated experiments, changing free parameters (cylinder cross-section, pipe length and diameter; capacitance and resistance; water volume and material of the container) or the initial conditions (water level; capacitor potential; water temperature).

These three experiments are based on elementary physics concepts such as capacitance, resistance, difference of potential and flux, represented by recurrent model structures. Table 1 identifies the similarities between the experiments whereas figure 4 shows one of the possible resulting VnR models, in which three elementary structures can be recognized:

Structure (a), composed of three variables connected through product and quotient relations, can be interpreted as the concept of capacitance ($C1$), e.g. an extensive quantity ($S1$) accumulated into a reservoir with specific geometrical properties produces an increase in the conjugate intensive quantity ($L1$).

Structure (b), composed of three variables connected through sum and subtraction relations, can be interpreted as the concept of difference of potential (ΔL), e.g. the level of an intensive quantity ($L1$) referred to the level of a homogeneous one ($L2$).

Structure (c), composed of three variables connected through product and quotient relations controlling the rate of change relations, corresponds to the concept of flux (F), favoured by an intensive quantity (ΔL) and hindered by a resistance parameter (R), which determines, through a feedback, the evolution of the process over time.

This activity gives students the opportunity to be introduced to a process-oriented approach to phenomena, using the VnR dynamic relation (rate of change), in addition to static ones (sum, product, subtraction and quotient).

Activity 3. A thought experiment with a complex model

The aim of activity 3 is to improve students' model-oriented thinking skills by means of

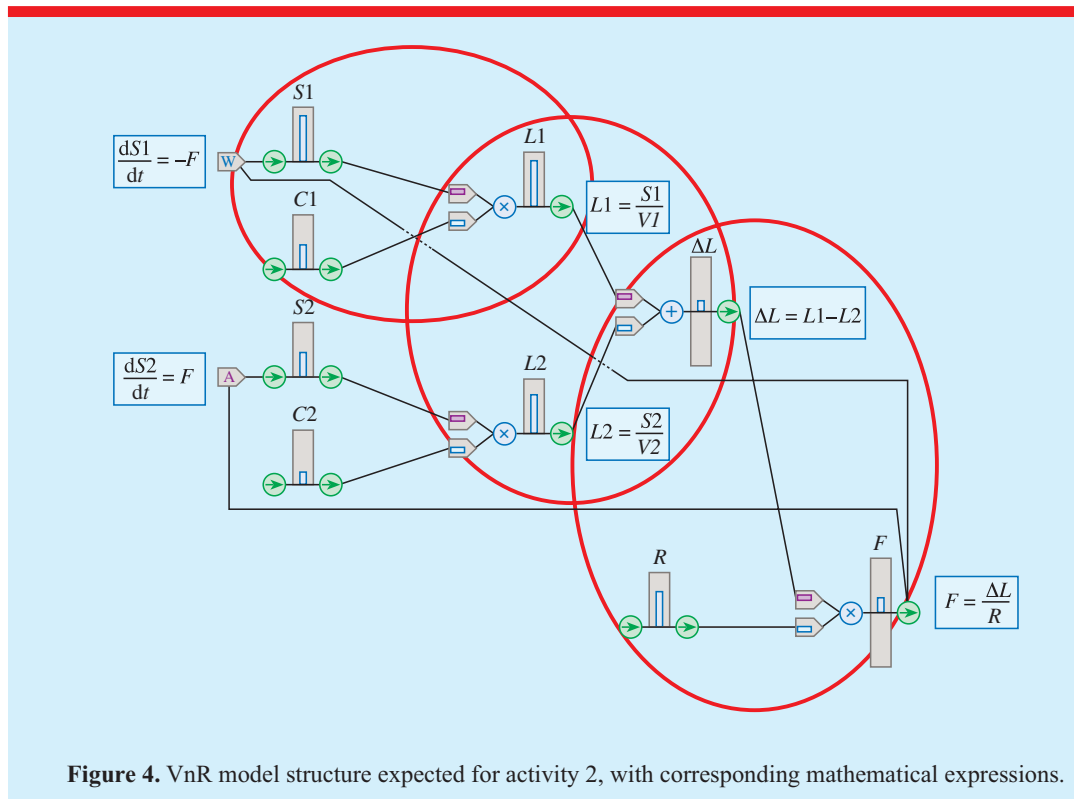


Figure 4. VnR model structure expected for activity 2, with corresponding mathematical expressions.

the structures encountered during the previous activities. The context is a thought experiment, i.e., with a known fact which is not shown or illustrated by the teacher, but that students are just invited to ‘imagine’. A suitable experiment is the study of the variation over time of water level in a tank fed by a tap and drained through a hole placed at a certain height from the basin bottom.

Figure 5 shows a possible model structure where the elementary structures are highlighted and labelled according to the classification of activity 2:

- Structure (a)* corresponds to the concept of capacitance,
- Structure (b)* corresponds to difference of potential,
- Structure (c)* corresponds to flux intensity and feedback.

Since the outward flux does not occur until the water level reaches the hole height, the model structure (b) employs a positive-only variable. The use of a positive/negative variable would mean allowing water inflow through the drain hole. As a consequence, flux intensity (c) is also

unidirectional and generates only a negative rate of change feedback, meaning that the water in the basin is wasted and not transferred, as was the case in activity 2.

As regards the concept of equilibrium, in this case we should talk about dynamic equilibrium, since the water level in the basin reaches a steady state due to the balance of the inward and outward fluxes, whereas activity 2 showed a static equilibrium achieved when the fluxes tended to zero.

Conclusions

The analysis of the models built by students and the discussions among them during a pilot experimentation with the pathway show that these activities introduce students to employing variables and relations to describe phenomena, and to make use of elementary structures in different contexts. In particular, working with VnR allows students to experience modelling and to be induced to interpret phenomena instead of simply describing them [1, 4]. Finally, it is noticeable that the quality of VnR model results was greatly improved by interaction between

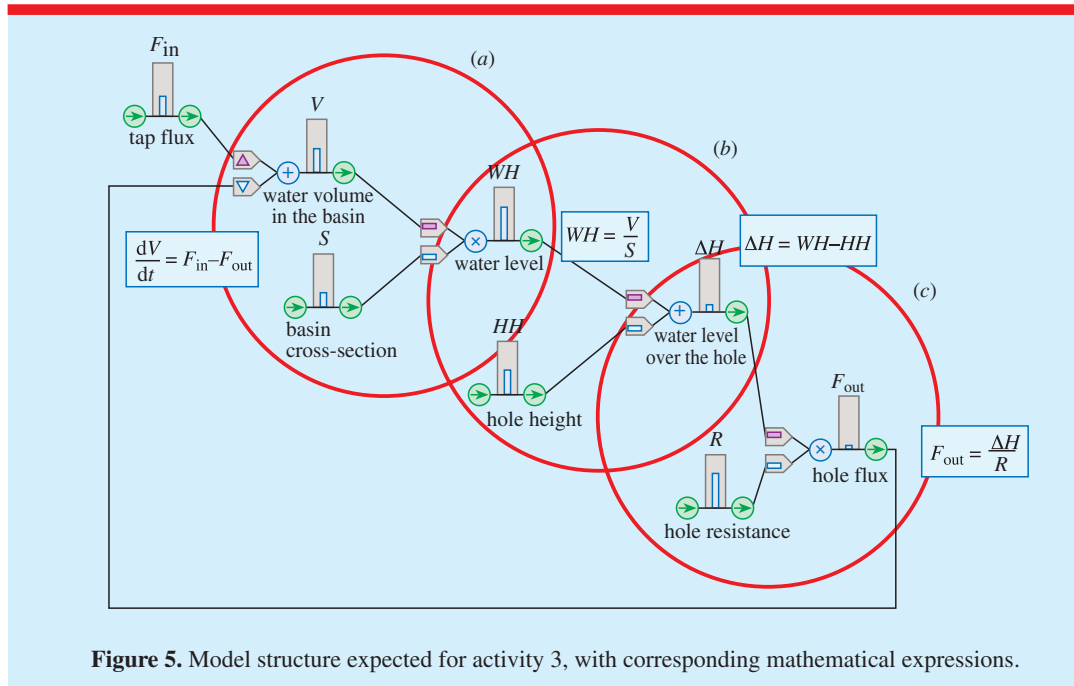


Figure 5. Model structure expected for activity 3, with corresponding mathematical expressions.

students. The main effect of this interaction is the creation of a 'common language' with several levels of abstraction, helpful for describing and interpreting phenomena.

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